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The Comparative Efficacy of Vitamin D from Irradiated Yeast and Cod-liver Oil for Growing Pigs, With Observations on Their Vitamin D Requirements

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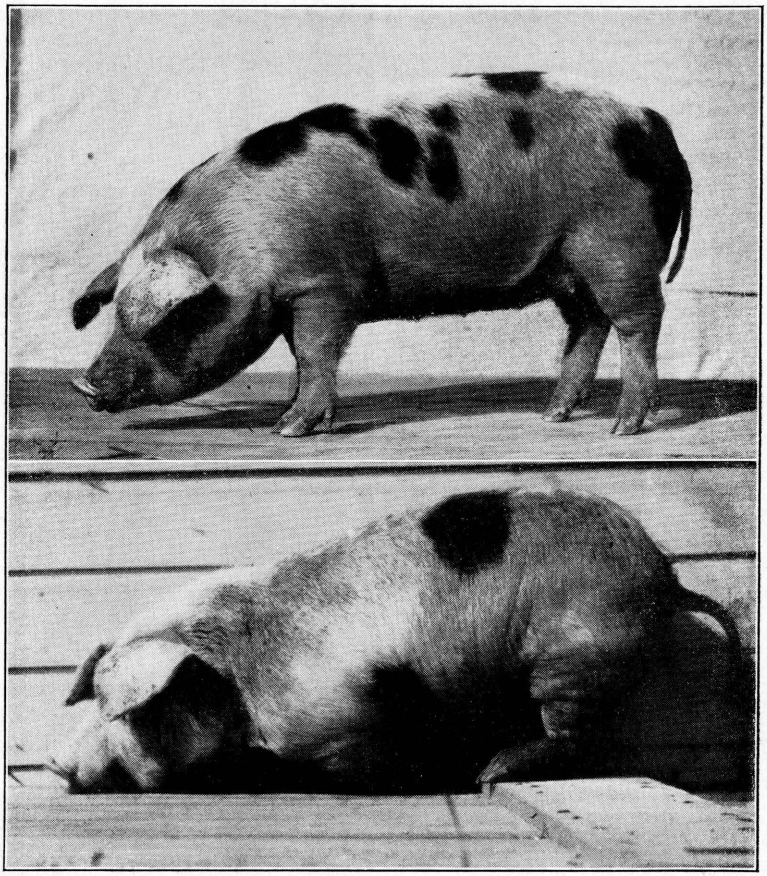

Healthy pig (top) and pig with rickets (bottom)

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THE COMPARATIVE EFFICACY OF VITAMIN D FROM IRRADIATED YEAST AND COD-LIVER OIL FOR GROWING PIGS, WITH OBSERVATIONS ON THEIR VITAMIN D REQUIREMENTS[1]

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Introduction

The importance of vitamin D for efficient growth and performance of swine has been pointed out by many workers in this and other countries. This vitamin, through its specific action in calcium and phosphorus metabolism and bone growth, is necessary for the production of a sound, well-developed skeleton, which is essential to profitable pork production.

The fact that common pig feeds, especially grains and plant protein supplements, are lacking in calcium, vitamin D, and to some extent, phosphorus accounts in part for the appearance of rickets and kindred deficiency symptoms under many practical conditions.

The vitamin D needs of swine are met when they are exposed to sufficient direct sunlight. Under such conditions, no additional vitamin D need be supplied through the feed. However, in instances where swine are confined indoors for one reason or another or do not receive sufficient exposure to direct sunlight (as in winter in certain parts of the country), some supplemental feed source of vitamin D is indicated.

A commonly recommended practice has been to feed sun-cured alfalfa meals or legume hays as supplemental sources of vitamin D. Such meals and hays will supply some vitamin D, but they cannot be considered dependable sources of this nutrient, because of their marked variation in vitamin D content. Products like fish oils or feeding oils that contain vitamin D and D-activated animal sterols can also be used as feed sources of this nutrient. The difficulty has been that there was very little information available on the quantitative requirements of swine for vitamin D; hence, heretofore it has not been possible to make intelligent recommendations on the amounts to be fed.

Science has also established that there are different forms of vitamin D. Not all of these forms of vitamin D are equally effective for all animals. For example, the form found in irradiated ergosterol or irradiated yeast (D_2) has been shown to be less efficient for chickens than the form found in cod-liver oil or irradiated animal sterol (D_3). On the other hand, it has been shown that the forms of vitamin D in irradiated yeast and cod-liver oil are equally effective for calves. Whether these forms of vitamin D are also comparable in efficacy for swine has not been definitely known.

The objectives of the experiments described in this bulletin were: first, to obtain information on the vitamin D requirements of growing and fattening pigs; and second, to compare the effectiveness of the vitamin D in irradiated yeast and in cod-liver oil.

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[2]Resigned.

Literature Review

Steenbock, Hart, and Jones (19) were the first to report that direct sunlight, by exerting antirachitic properties, was a factor in swine nutrition and thus established that vitamin D was essential to pork producton. Shortly thereafter, Maynard, Goldberg, and Miller (12) reported that cod-liver oil corrected and alleviated poor bone development and stiffness which frequently occurred in growing pigs fed rations containing an abundance of calcium and phosphorus. Similar observations were reported from this station by Bohstedt et al. (6). Several other investigators, Loeffel and associates (10), Sinclair (17), Dunlap (7), Skelley (18), Aubel and Hughes (1), Johnson and Palmer (8, 9), Senior (16), and Bethke et al. (3), have reported on the importance of vitamin D in swine nutrition. Of particular significance is the work of Johnson and Palmer (8, 9), and Senior (16), which established definitely that the pig has a fundamental need for vitamin D.

That the amount of vitamin D required is influenced by the calcium and phosphorus content of the ration as well as by the ratio in which these elements are present, has been shown by work at this Station (3) as well as by Aubel and Hughes (1), and Johnson and Palmer (9). Within limits, the need for vitamin D is inversely proportional to the calcium and phosphorus content of the ration. However, even when the feed supplies adequate amounts of calcium and phosphorus and in a satisfactory ratio, it is apparent from the work of Johnson and Palmer (9) and Senior (16) that the pig needs some vitamin D.

Johnson and Palmer (9) reported that rickets in pigs was cured by exposing the animals to an average of 45 minutes per day of January sunshine for two weeks in St. Paul, Minnesota. These authors did not try shorter exposures. The same authors also reported that the feeding of 5 percent of sun-cured alfalfa hay, containing 0.39 units of vitamin D per gram, or the equivalent of about 38 units of vitamin D per pig per day, did not protect against rickets; whereas, pigs fed a ration with 5 percent of alfalfa hay containing 0.85 units of vitamin D per gram did not become rachitic, as judged by blood analysis and gross external manifestations. The same amount of hay in the ration failed to cure rickets.

On the other hand, the same investigators reported that sun-cured alfalfa hay containing 1.46 units of vitamin D per gram was effective in curing rickets at a 5 percent level of the ration. The latter amount of hay supplied the equivalent of about 200 to 250 units of vitamin D daily per pig. According to the foregoing observations, a ration which contained approximately 19 to 20 units of vitamin D from sun-cured alfalfa hay per pound of feed protected against rickets but failed to cure the deficiency; whereas a level of 33 units of vitamin D from alfalfa hay per pound of ration was effective in curing rickets, as judged by blood analysis and gross appearance. Other reports have appeared in the literature that cod-liver oil and exposure to direct sunlight prevented and cured rachitic manifestations in swine. It is, however, impossible to calculate or estimate what the minimum quantitative requirements of vitamin D were either to prevent or to cure rachitic symptoms.

There are numerous reports in the literature which show that there are several forms of vitamin D and that some forms are more effective for certain species of animals than others. For example, Mussehl and Ackerson (13), Massengale and Nussmeier (11), Russell and Klein (14), Steenbock, Kletzien, and Halpin (20), Russell, Taylor, and Wilcox (15), and Bethke, Record, and Kennard (5) have shown that the vitamin D of cod-liver oil is more effective for the chicken than the vitamin D of irradiated ergosterol or irradiated yeast.

Waddell (21) and Bethke, et al. (4) showed that the vitamin D of irradiated cholesterol and cod-liver oil are comparable in efficacy for chickens. On the other hand, Bechdel and associates (2) reported that the forms of vitamin D in irradiated yeast and cod-liver oil are equally effective for calves.

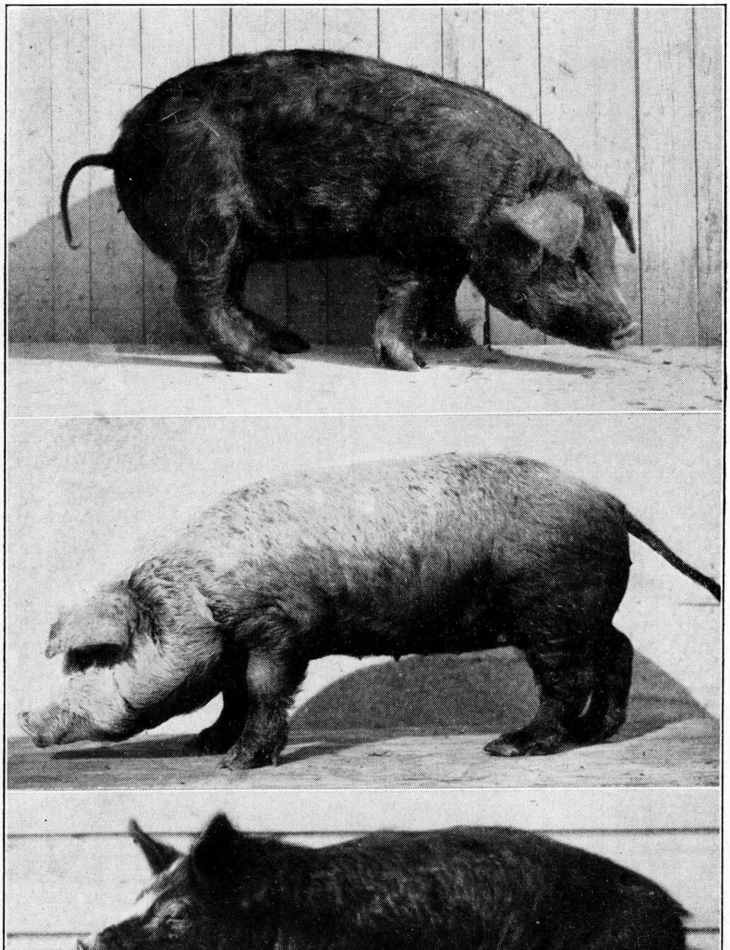

Fig. 1.—Vitamin D deficiency results in rickets; the greater the deficiency the more severe the symptoms (top to bottom)

The work of Johnson and Palmer (9) also indicates that the form of vitamin D in sun-cured alfalfa hay is effective for swine. Since the form of vitamin D in plant tissue is recognized to be comparable to the form present in irradiated yeast, it might be supposed that the yeast and cod-liver oil forms of vitamin D are equally effective for swine as they are for calves.

Experimental Procedure

Five separate trials were conducted. These are listed by number in the order in which they were carried out. Pigs of comparable breeding and nutritional history were used in each trial except in trial 1. In the latter instance, the pigs were obtained from several sources and varied as to breeding and nutritional history.

The pigs were put on the experimental rations either immediately or shortly after weaning, when 8 to 10 weeks of age. Prior to being put on experiment, they were immunized against cholera. Division into experimental lots was made on the basis of litter, sex, and weight. Each pig was confined to an indoor pen provided with a concrete floor, one-half of which was covered with a wood floor. The pens were all of the same size. No bedding was used.

The pigs were individually hand-fed twice each day all the feed they would consume. Individual live weights were taken on three successive days at the start and at the close of a trial and every 2 weeks intervening. Animals that died or were removed before the trial was completed were examined for gross pathological lesions. If the animal had been on the experimental ration for 8 weeks or more, the femurs were removed and preserved by freezing for future physical and chemical analyses.

All trials were conducted in the same building from which all sunlight was excluded.

Calcium and inorganic phosphorus determinations were made on the blood serum of the individual pigs at different intervals in the five trials. In trials 1 and 2, the determinations were made at approximately the middle and just prior to the close of the experiment. In trials 3, 4, and 5 the determinations were made just prior to supplemental feeding and at 4 week intervals thereafter. Phosphatase determinations were also made on the blood serum samples in trials 3, 4, and 5. Calcium was determined by the Clark-Collip method,[3] inorganic phosphorus by the Fiske-Subbarow procedure,[4] and phosphatase by the Bodansky method.[5]

At the close of the trials the animals were slaughtered and a femur was removed from each animal. The femurs were kept in a refrigerator at approximately 28° F. They were cleaned of adhering tissue, and in trials 3, 4, and 5, determinations of maximum length and smallest diameter of the femurs were made by means of a micrometer. The volume of the bone was determined by the difference between the weights of the bone in air and in water. These measurements were made with a Toledo balance calibrated to read to 1 gram. Several sources of error were encountered when weighing the bones in water—namely, air bubbles collected around the bone, especially in the crevices, and some water was absorbed. However, with care and rapid reading of

[3]Clark, E. P., and J. B. Collip. 1925. A study of the Tisdall method for the determination of blood serum calcium with a suggested modification. Jour. Biol. Chem. 63: 461-464.

[4]Fiske, C. H., and Y. Subbarow. 1925. The colormetric determination of phosphorus. Jour. Biol. Chem. 66: 375-400.

[5]Bodansky, A. 1933. Phosphatase studies II. Determination of serum phosphatase. Factors influencing the accuracy of the determination. Jour. Biol. Chem. 101: 93-104.

the weight, both these sources of error were minimized and a fairly accurate measurement was obtained. The breaking strength was determined with an Olsen dynamometer with the bone resting on points 4½ inches apart.

After the physical measurements had been completed, the entire femur was crushed in a bone cutter and dried for 24 hours in an electric oven operating at 100° C. The dried samples were then extracted with three applications of warm alcohol and sufficient applications of ether to remove enough fat and lipoid material to permit the sample to be finely ground in a burr mill. To insure the complete removal of fats and lipoids, a portion of the finely ground sample of each bone was further extracted for 18 to 24 hours with ether in a Soxhlet extractor. Duplicate ash determinations were made on the moisture and fat-free samples of the bones under uniform conditions of time and temperature.

The basal rations used in the several trials are shown in table 1. Ration 1, used in trials 1 and 2, was designed with a wide calcium-phosphorus ratio because previous work at this Station (3) had indicated that such a ration was more rachitic in effect than one possessing a narrower ratio. It analyzed 1.16 percent calcium and 0.40 percent phosphorus, with a calcium to phosphorus ratio of 2.90. Ration 2, used in trials 3, 4, and 5, had an average calcium-phosphorus ratio of 1.24. It contained between 0.56 and 0.60 percent calcium and 0.45 to 0.49 percent phosphorus. The dried skimmilk was reduced from 5.0 percent in ration 1 to 3.0 percent in ration 2, partly to overcome the diarrhea noted in trials 1 and 2 during the first few weeks after the start of the experiments. Niacin was added because an enteritis was encountered in a preliminary trial with the same type basal ration. Manganese and iron were added to make certain that these elements were not limiting factors.

The experimental rations were mixed in amounts to last for 3 to 4 weeks' feeding. The cod-liver oil was diluted with sufficient corn oil so that approximately 0.25 percent of the oil mixture supplied the desired unitage of vitamin D. An equivalent amount of corn oil was added to the ration of the basal- and yeast-fed groups. The irradiated yeast was incorporated in the form of a yeast-soybean oil meal premix.

The cod-liver oil and irradiated yeast used in the five trials were all from the same supply. The stock supply of cod-liver oil and irradiated yeast was stored in a refrigerator. Both the cod-liver oil and irradiated yeast were assayed for vitamin D with rats against Reference cod-liver oil. At the start of the trials, the vitamin D potency of the irradiated yeast had not been determined accurately but repeated line-test and bone-ash assays showed the irradiated yeast to contain 3500 U. S. P. units and the cod-liver oil, 225 U. S. P. units of vitamin D per gram.

Trial 1

The pigs used in this trial were of mixed breeding. They were farrowed in the fall and reared under different management and feeding conditions. They were estimated to be between 8 and 10 weeks of age when placed on the experimental rations.

The trial consisted of seven lots of eight pigs each. Three lots were fed ration 1 (table 1) supplemented with different levels of irradiated yeast; three lots were fed the basal ration supplemented with graded amounts of cod-liver oil; and a control lot was fed the unsupplemented basal ration. The trial was of 18 weeks duration—starting the latter part of November and terminating the early part of April.

TABLE 1.—Composition of basal rations

	1	2
Ground yellow corn	72.00	75.00
Toasted soybean oil meal, 44%	20.00	20.00
Dried skimmilk	5.00	3.00
Steamed bonemeal	....	0.75
Ground limestone	2.50	0.75
Iodized salt	0.50	0.50

Twenty grams of ferrous sulfate (technical grade) and 5 grams of manganese sulfate were added to each 100 pounds of ration.

Niacin was added to ration 1 at the rate of 3.0 grams per 100 pounds until the pigs attained an average weight of 100 pounds, when it was reduced to 1.5 grams.

Niacin was added to ration 2 at the following rates per 100 pounds: preliminary feed period, 3.00 grams; start of test to an average weight of 100 pounds, 1.50 grams; and from an average weight of 100 pounds to end of test, 0.75 grams.

Ration 1 was used in trials 1 and 2, and ration 2 in trials 3, 4, and 5.

One pig in the control lot (lot 1) showed definite signs of stiffness after 5 weeks on test. Three other pigs in the same lot (lot 1) showed similar rachitic symptoms the following 2 weeks and by the eleventh week, seven of the eight pigs showed deficiency symptoms. One pig in the control lot (lot 1) completed the trial without any evidence of vitamin D deficiency, either on gross examination or from the blood serum analysis and the breaking strength and ash determinations on the femurs.

In the lowest yeast-fed lot (lot 5) four pigs showed rachitic symptoms between the sixth and eighth weeks. Another pig in the same lot was stiff by the twelfth week. By the seventeenth week, six of the eight pigs exhibited gross symptoms of vitamin D deficiency. Two pigs (lot 5) completed the test without showing any signs of a vitamin D deficiency, as judged by gross appearance and behavior and by blood and bone analysis.

One pig on the intermediate yeast level (lot 6) showed signs of stiffness by the ninth week, and it did not recover before the trial was terminated. This pig, however, continued to make good gains. A second pig in the lot (lot 6) was slightly stiff for a few weeks, but it recovered before the close of the test. It is not known whether the slight stiffness was due to an injury or a deficinecy of vitamin D.

None of the pigs in the high yeast- (lot 7) or cod-liver oil-fed lots (lots 2, 3, and 4) showed any gross symptoms of a vitamin D deficiency. One pig in the low cod-liver oil-fed lot (lot 2) was lame in one rear leg for about a week. It was thought that the lameness was due to an injury.

It is evident from the data presented in table 2 that there was no significant difference between the average daily gain and feed requirements per 100 pounds of gain of any of the lots which were fed 44 or more U. S. P. units of vitamin D per pound of feed, either from irradiated yeast or cod-liver oil. The general average performance of the pigs fed the basal ration supplemented with 22 U. S. P. units of vitamin D per pound of feed from irradiated yeast (lot 5) was not significantly different than the average performance of the pigs fed the unsupplemented basal ration (lot 1).

TABLE 2.—Gains and feed requirements. Trial 1

Lot No.	Vitamin D supplement additions per 100 lb. basal ration	Vitamin D per lb. feed	Av. daily intake of vitamin D	Pigs per lot	Pigs died	Av. initial weight	Av. final weight	Av. daily gain	Av. daily feed	Feed required per 100 lb. gain	Remarks
		Units	*Units*	*No.*	*No.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	
1	None	0	0	8	0	42.3	156.5	0.91	3.71	416	All pigs except one were stiff.
2	20.18 gm. cod-liver oil	45	193	8	0	42.8	191.7	1.18	4.29	367	Normal. One pig lame for 1 week.
3	40.37 gm. cod-liver oil	91	393	8	0	43.0	194.6	1.20	4.32	363	Normal.
4	80.75 gm. cod-liver oil	182	801	8	0	42.1	197.9	1.24	4.40	358	Normal.
5	0.63 gm. irradiated yeast	22	77	8	0	41.5	151.3	0.87	3.49	412	All pigs except two were stiff.
6	1.26 gm. irradiated yeast	44	193	8	0	41.6	194.3	1.21	4.39	366	One pig was stiff and one slightly stiff for a few weeks.
7	2.52 gm. irradiated yeast	88	372	8	0	41.7	188.7	1.17	4.23	369	Normal.

TABLE 3.—Physical measurements and ash contents of femurs and blood serum analyses. Trial 1

Lot No.	Vitamin D supplement additions per 100 lb. basal ration	Vitamin D per lb. feed	Av. daily intake of vitamin D	Pigs per lot	Femur measurements and ash contents					Blood serum analyses*			
					Av. weight	Av. volume	Av. breaking strength	Av. ash	Av. ash per cc. volume	Ca. per 100 ml.		P. per 100 ml.	
										Mid†	Close‡	Mid†	Close‡
		Units	*Units*	*No.*	*Gm.*	*Cc.*	*Lb.*	*Pct.*	*Gm.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*
1	None	0	0	8	142	123	338±82§	53.1±1.68§	0.613	13.4	12.6	2.4	3.4
2	20.18 gm. cod-liver oil	45	193	8	165	135	601±76	58.0±1.29	0.709	14.4	14.5	5.3	5.6
3	40.37 gm. cod-liver oil	91	393	8	178	147	685±59	58.3±0.83	0.706	14.4	15.0	5.8	6.2
4	80.75 gm. cod-liver oil	182	801	8	180	150	612±46	58.5±0.88	0.702	14.5	15.3	5.5	6.4
5	0.63 gm. irradiated yeast	22	77	8	160	136	438±86	55.1±1.62	0.648	13.2	14.2	3.8	4.1
6	1.26 gm. irradiated yeast	44	193	8	189	155	651±69	57.8±1.05	0.705	14.6	14.7	3.9	4.9
7	2.52 gm. irradiated yeast	88	372	8	173	141	713±83	59.2±0.69	0.726	14.8	15.3	4.6	5.7

*Mean values of the individual samples.
†Determinations made between the 8th and 9th week on experiment.
‡Determinations made at the close of the experiment.
§Standard error of the mean.

The femur and blood analysis data are given in table 3. There was no significant difference in the breaking strength or the ash content of the femurs between any of the lots fed 44 U. S. P. units or more of vitamin D per pound of feed. The lower breaking strength and ash values of lot 5 show that a level of 22 U. S. P. units of vitamin D per pound of feed from irradiated yeast was inadequate. The blood serum analysis data show a reduction in the average calcium and a definite decrease in the inorganic phosphorus values on the unsupplemented basal ration (lot 1). There is also an indication that 22 U. S. P. units of vitamin D per pound of feed from irradiated yeast was not adequate to maintain normal calcium and inorganic phosphorus levels in the blood serum throughout the experiment. It is of interest to note that, in general, the inorganic phosphorus blood serum values of the cod-liver oil fed pigs were higher than those fed irradiated yeast. We are unable to account for this difference when the results of the other trials are taken into consideration. The femur and blood data are in close agreement with the performance data (table 2) and suggest that the forms of vitamin D in irradiated yeast and cod-liver oil are approximately equally effective for pigs.

Trial 2

The pigs in trial 2 were from crossbred (Duroc Jersey × Hampshire) gilts all bred to the same boar. They were farrowed the latter part of March and, with their dams, had access to pasture. When the pigs were 8 to 10 weeks old they were confined in the experimental pens and fed basal ration 1 (table 1) before the vitamin D supplements were added. The basal ration was fed to a like number of pigs in each experimental lot for either 3 or 4 weeks.

The trial consisted of eight lots of seven pigs each. Three lots were fed ration 1, supplemented with cod-liver oil to supply either 22.5, 67.5, or 135.0 U. S. P. units of vitamin D per pound of feed. Four lots had their ration supplemented with either 17.5, 52.5, 105.0, or 157.5 U. S. P. units of vitamin D per pound from irradiated yeast. The unsupplemented basal ration was fed to one lot. The experimental rations were fed for 17 weeks—starting June 25 and terminating October 22.

Four weeks after vitamin D feeding was started, two pigs in the control lot (lot 1) showed deficiency symptoms in the form of stiffness. One week later a third pig in the same lot was similarly affected. Three additional pigs in the lot exhibited varying degrees of stiffness by the ninth, tenth, and thirteenth weeks. At the close of the test, six of the seven pigs in this control lot (lot 1) showed external symptoms of a vitamin D deficiency. The pig which completed the test without visible deficiency symptoms also had normal calcium and inorganic phosphorus blood values and a strong femur with normal ash content.

In the lowest cod-liver oil-fed lot (lot 2—22.5 U. S. P. units per pound of feed), four of the seven pigs showed varying degrees of stiffness during the trial. These symptoms first appeared in three pigs between the eighth and tenth weeks, and in the fourth pig, by the fifteenth week. In lot 3, fed 67.5 U. S. P. units of vitamin D per pound of feed, one case of slight stiffness appeared towards the end of the test. In the lowest yeast-fed lot (lot 5—17.5 U. S. P. units per pound of feed) five of the seven pigs showed external symptoms of a vitamin D deficiency in the form of stiffness. The first symptoms appeared about the same time as in the control lot (lot 1) and their severity was about of the same order toward the close of the test.

TABLE 4.—Gains and feed requirements. Trial 2

Lot No.	Vitamin D supplement additions per 100 lb. basal ration	Vitamin D per lb. feed	Av. daily intake of vitamin D	Pigs per lot	Pigs died	Av. initial weight*	Av. final weight	Av. daily gain	Av. daily feed	Feed required per 100 lb. gain	Remarks
		Units	*Units*	*No.*	*No.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	
1	None	0.0	0	7	0	57.6	137.9	0.67	3.04	473	All pigs except one were stiff.
2	10.0 gm. cod-liver oil	22.5	74	7	0	57.4	156.4	0.83	3.28	402	Four pigs showed varying degrees of stiffness.
3	30.0 gm. cod-liver oil	67.5	252	7	0	57.1	179.0	1.02	3.73	368	One pig slightly stiff.
4	60.0 gm. cod-liver oil	135.0	653	7	0	57.8	219.1	1.35	4.84	357	Normal.
5	0.5 gm. irradiated yeast	17.5	47	7	0	56.4	126.7	0.59	2.70	517	All pigs except two were stiff.
6	1.5 gm. irradiated yeast	52.5	150	7	0	56.4	141.9	0.72	2.85	400	Three pigs showed varying degrees of stiffness.
7	3.0 gm. irradiated yeast	105.0	354	7	1	58.7	163.0	0.88	3.37	399	One pig slightly stiff.
8	4.5 gm. irradiated yeast	157.5	605	7	0	60.0	179.2	1.00	3.84	380	Normal.

*Weights when supplemental feeding was started. The average initial weights of the pigs that lived, when put on the basal ration, were 40.3, 39.9, 38.8, 40.9, 38.4, 39.1, 41.3, and 40.1 pounds for lots 1 to 8, respectively.

Increasing the vitamin D from yeast from 17.5 to 52.5 U. S. P. units per pound of feed (lot 6) delayed the appearance of external deficiency symptoms and their severity and reduced the number of pigs affected. However, it required more than 105 U. S. P. units per pound of feed from irradiated yeast to prevent completely the appearance of any external deficiency symptoms. One pig in lot 7 died from a ruptured bladder shortly after vitamin D feeding was started. No other mortality occurred in any of the other lots.

The average daily gains and feed requirements per unit of gain (table 4) of the cod-liver oil-fed pigs were, in general, better than those of the pigs on nearly comparable levels of vitamin D from irradiated yeast. On the basis of vitamin D supplementation per pound of feed, it appears that irradiated yeast was not so effective in preventing external deficiency symptoms as cod-liver oil. However, the apparent differences between the irradiated yeast- and cod-liver oil-fed lots are not as great as the results indicate when the actual average daily intake of vitamin D from the two sources is taken into consideration. The average daily intake of vitamin D from cod-liver oil from lots 2, 3, and 4 was 74, 252, and 653 U. S. P. units and from irradiated yeast for lots 5, 6, 7, and 8 was 47, 150, 354, and 605 U. S. P. units, respectively. The pigs in lots 2 and 3 (cod-liver oil) had approximately a 56 percent and 68 percent greater intake of vitamin D than the pigs in lots 5 and 6 (irradiated yeast), respectively. A comparison of lot 3 (cod-liver oil) and lot 7 (irradiated yeast) shows that the vitamin D supplementation per pound of feed in the latter lot (lot 7) was 55 percent greater than that of the former lot (lot 3), whereas the actual average daily intake of lot 7 was only 40 percent greater than that of lot 3.

The pigs in the irradiated yeast-fed lots did not, on the average, appear as thrifty as those in the cod-liver oil-fed lots. This was particularly true in lots 7 and 8 where in each case a pig, without showing any deficiency symptoms as judged either by general behavior or blood serum and femur analysis, did poorly which in part accounts for the smaller average daily gains and increased feed requirements per 100 pounds of gain of those lots in comparison with lots 3 and 4, fed cod-liver oil. Furthermore, one pig in lot 8 developed a large umbilical hernia. To what extent this condition affected the growth and performance of the pig is not known.

The results of the femur analyses, shown in table 5, indicate that it required a greater unitage of vitamin D per pound of feed from irradiated yeast than from cod-liver oil to give approximately the same breaking strength and bone ash values. On the basis of vitamin D supplementation per pound of feed, the results indicate that it required about again as many units from irradiated yeast as from cod-liver oil to give the same bone values. However, when the results are compared on the basis of average daily intake of vitamin D, it is apparent that the two forms of vitamin D are more nearly comparable in efficiency than the data in table 5 indicate.

The femur data (table 5) also indicate that it required somewhat more than 67.5 U. S. P. units of vitamin D per pound of feed, or an average daily intake of 252 U. S. P. units from cod-liver oil to give maximum breaking strength, bone ash, and ash per unit volume values. These values are higher than those noted in trial 1, in which case 44 to 45 U. S. P. units of vitamin D per pound of feed from irradiated yeast and cod-liver oil, respectively, or an average daily intake of 192 U. S. P. units, was slightly below the minimum level or intake which was adequate to produce femurs with maximum breaking

TABLE 5.—Physical measurements and ash contents of femurs and blood serum analyses. Trial 2

Lot No.	Vitamin D supplement additions per 100 lb. basal ration	Vitamin D per lb. feed	Av. daily intake of vitamin D	Pigs per lot	Femur measurements and ash contents: Av. weight	Av. volume	Av. breaking strength	Av. ash	Av. ash per cc. volume	Blood serum analyses*: Ca. per 100 ml. Mid†	Ca. per 100 ml. Close‡	P. per 100 ml. Mid.†	P. per 100 ml. Close‡
		Units	*Units*	*No.*	*Gm.*	*Cc.*	*Lb.*	*Pct.*	*Gm.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*
1	None	0.0	0	7	144	129	290±75§	52.3±1.87§	0.590	13.6	13.6	4.3	3.0
2	10.0 gm. cod-liver oil	22.5	74	7	155	135	331±31	56.9±0.73	0.651	14.0	13.7	4.3	3.5
3	30.0 gm. cod-liver oil	67.5	252	7	182	155	487±48	59.4±0.77	0.696	14.3	15.0	4.9	5.1
4	60.0 gm. cod-liver oil	135.0	653	7	218	173	621±31	61.0±0.33	0.745	15.3	15.4	5.2	6.6
5	0.5 gm. irradiated yeast.	17.5	47	7	141	125	265±43	53.2±1.53	0.600	14.6	14.1	3.8	3.7
6	1.5 gm. irradiated yeast.	52.5	150	7	155	136	327±37	56.0±0.67	0.637	14.1	13.8	4.5	3.8
7	3.0 gm. irradiated yeast.	105.0	354	6	173	146	443±70	57.7±0.90	0.685	14.6	14.6	4.7	4.6
8	4.5 gm. irradiated yeast.	157.5	605	7	185	156	557±90	49.2±0.90	0.700	15.4	15.0	4.9	4.9

*Values given are mean values of the individual samples.
†Determinations made between the 6th and 7th week after start of supplemental feeding.
‡Determinations made during last week of experiment.
§Standard error of mean.

strength and ash values. This difference in vitamin D requirements between trials 1 and 2 could have been due to a difference in vitamin D storage when the pigs were placed on experiment. In trial 1, the pigs were started on their respective rations shortly after weaning; whereas in trial 2, the pigs were fed the unsupplemented basal ration for 3 or 4 weeks before vitamin D feeding was started.

The blood serum analysis data (table 5) show that it required on the order of 67.5 U. S. P. units of vitamin D per pound of feed or an average daily intake for the test of 252 U. S. P. units to prevent a decrease in the calcium and inorganic phosphorus content of the serum during the experiment. The inorganic phosphorus decreased more than the calcium on sub-optimum intakes of vitamin D. This is in accord with the observations of trial 1. The results also show, as in trial 1, that cod-liver oil was more effective in maintaining a high level of inorganic phosphorus in the blood serum than was irradiated yeast.

Trial 3

The pigs used in this test were from Hampshire sows bred to the same Berkshire boar. They were farrowed in September and weaned when 56 to 60 days old. The dams and their litters had access to the same pasture and were fed the same feed.

Following weaning, the pigs were divided into eight lots of seven pigs each and confined to the indoor experimental pens. Basal ration 2 was fed for 4 weeks to all pigs before it was supplemented either with three different levels of cod-liver oil or four different levels of irradiated yeast. One control lot of pigs (lot 1) was continued on the basal ration. The experimental rations (table 6) were fed for 17 weeks—starting December 18 and closing April 15.

On the twenty-second day of the experimental period, one pig in lot 1 (basal ration 2) showed tetany and died 4 days later. Another pig in the same lot (lot 1) showed tetany and stiffness on the thirtieth day but continued to live for 60 more days, with very little intake of feed. A third pig in the same lot had an attack of tetany on the thirty-second day and died 4 days later. On the thirty-sixth day after the start of the test, a fourth pig in lot 1 was found in a state of tetany from which it did not recover. A fifth pig in the same lot showed evidence of stiffness after 48 days and exhibited tetany on 2 succeeding days, 15 and 16 days later. This animal died 2 weeks following his last observed attack of tetany. The remaining two pigs in lot 1 showed evidence of rickets by the seventh and eleventh weeks. Both of these animals survived to the close of the test, but with a greatly reduced feed intake and gradual loss in weight.

In the lowest cod-liver oil lot (lot 2, 22.5 U. S. P. units per pound of feed) and the lowest irradiated yeast lot (lot 5, 26.5 U. S. P. units per pound of feed) each had five pigs which showed gross rachitic symptoms. Of the five affected pigs in lot 2 (cod-liver oil) one exhibited deficiency symptoms after 8 weeks, three after 12 weeks, and one after 14 weeks of vitamin D feeding. Of the three pigs which were stiff after the twelfth week, one died from tetany during the sixteenth week. The five affected pigs in lot 5 (26.5 U. S. P. units per pound of feed from irradiated yeast) showed gross deficiency symptoms in the following order after vitamin D feeding was started; two at the end of 12 weeks, two at the end of 14 weeks, and one at the close of 16 weeks. The two earliest affected pigs (lot 5) died during the fifteenth and sixteenth weeks. Although tetany was not actually observed in either of these animals, it was thought, from their appearance after death, that both had succumbed during an attack of tetany.

Two pigs in lot 3 (45 U. S. P. units of vitamin D per pound of feed from cod-liver oil) exhibited tetany during the twelfth week after vitamin D feeding from which they did not recover. The remaining pigs in this lot finished the trial without showing any external symptoms of rickets. One pig in lot 6 (53 U. S. P. units of vitamin D per pound of feed from irradiated yeast) went off feed during the third week of vitamin D feeding and was found dead in the pen the following week. Post-mortem examinations suggested that the animal probably died during an attack of tetany. Another pig in lot 6 was observed to have three tetanic convulsions on the same day during the last week of the test and died shortly after the last attack. A third pig in the same lot went off feed during the fifteenth week showing evidence of slight stiffness in his rear legs. The other four pigs in lot 6 completed the test without showing any gross symptoms of a vitamin D deficiency. All of the pigs in lot 4 (90 U. S. P. units of vitamin D per pound of feed from cod-liver oil) and lots 7 and 8 (106 and 212 U. S. P. units of vitamin D per pound of feed from irradiated yeast, respectively) finished the test without showing any gross symptoms of a vitamin D deficiency.

One pig in lot 8, although completing the test without showing symptoms of a vitamin D deficiency as judged by outward appearance and blood serum and femur analysis, was omitted from the data in table 6, 7, and 8 because of general unthriftiness. It gained only 38 pounds in the 17 weeks on test.

The average gain and feed data of seven of the eight lots are presented in table 6. The data for lot 1 (control) are omitted because only two pigs survived to the close of the test and these were in a critical state. There was no significant difference either in the average daily gains or the average amount of feed required to produce 100 pounds of gain between any of the lots (lots 4, 7, and 8) which received 90 U. S. P. units or more of vitamin D per pound of feed either from cod-liver oil or irradiated yeast.

On lower levels of vitamin D per pound of feed, some of the pigs in either the cod-liver oil- or irradiated yeast-fed lots showed evidence of vitamin D deficiency either in the form of tetany, stiffness, or a combination of both. The differences in average daily gains and in feed requirements per 100 pounds of gain between lots 2 and 5 (22.5 and 26.5 U. S. P. units of vitamin D from cod-liver oil and irradiated yeast per pound of feed, respectively) and lots 3 and 6 (45 and 53 U. S. P. units of vitamin D from cod-liver oil and irradiated yeast per pound of feed, respectively) are not significant because of the variation in the individual performance of the pigs in each lot.

The physical measurements and bone ash data of the femurs, presented in table 7, show that 90 U. S. P. units or more of vitamin D per pound of feed either from cod-liver oil or irradiated yeast were required to produce a bone of near maximum breaking strength and ash content. The data also indicate that the two forms of vitamin D were approximately equally effective for bone growth and calcification, since there was no consistent difference in any of the values between lots fed nearly comparable levels of vitamin D, either from cod-liver oil or irradiated yeast. If any great difference in efficacy had existed between the two forms of vitamin D, one would have expected the

TABLE 6.—Gains and feed requirements. Trial 3

Lot No.	Vitamin D supplement additions per 100 lb. basal ration	Vitamin D per lb. feed	Av. daily intake of vitamin D	Pigs per lot	Pigs died	Av. initial weight †	Av. final weight *	Av. daily gain *	Av. daily feed *	Feed required per 100 lb. gain *	Remarks
		Units	*Units*	*No.*	*No.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	
1	None	0	0	7	5	63.3	....	....	....	....	All severely rachitic; five died with tetany.
2	10.000 gm. cod-liver oil	22.5	78	7	1	65.8	156.0	0.78	3.48	501	Five stiff; one died with tetany.
3	20.000 gm. cod-liver oil	45.0	208	7	2	67.3	219.4	12.8	4.63	364	Two died with tetany.
4	40.000 gm. cod-liver oil	90.0	418	7	0	64.4	224.9	1.35	4.65	356	Normal.
5	0.757 gm. irradiated yeast	26.5	85	7	2	63.7	144.7	0.68	3.23	478	Five stiff; two died with probable tetany.
6	1.514 gm. irradiated yeast	53.0	197	7	1	64.7	179.1	1.00	3.72	397	Two died with tetany; one slightly stiff.
7	3.028 gm. irradiated yeast	106.0	488	7	0	65.3	211.1	1.23	4.60	377	Normal.
8	6.056 gm. irradiated yeast	212.0	1083	6	0	65.5	234.5	1.42	5.11	360	Normal.

*On basis of pigs living at close of experiment, except in case of lot 6 values based on six pigs including the one that died during the last week of the trial.

†Weights when supplemental feeding was started. The average initial weights when put on the basal ration were 39.4, 40.3, 40.5, 40.1, 40.6, 40.1, 40.3, and 41.5 pounds for lots 1 to 8, respectively.

TABLE 7.—Physical measurements and ash contents of femurs. Trial 3

Lot No.	Vitamin D supplement additions per 100 lb. basal ration	Vitamin D per lb. feed	Av. daily intake of vitamin D	Pigs per lot*	Av. weight	Av. volume	Av. length	Av. smallest diameter	Av. breaking strength	Av. ash	Av. ash per cc. volume
		Units	*Units*	*No.*	*Gm.*	*Cc.*	*Cm.*	*Cm.*	*Lb.*	*Pct.*	*Gm.*
1	None	0	0	4	99	89	15.3	1.70	233±48†	52.9±1.63†	0.583
2	10.000 gm. cod-liver oil	22.5	78	7	161	133	17.6	1.85	468±89	57.8±1.16	0.695
3	20.000 gm. cod-liver oil	45.0	208	7	200	155	19.3	2.02	844±48	61.6±0.16	0.792
4	40.000 gm. cod-liver oil	90.0	418	7	241	184	20.1	2.24	1049±47	63.3±0.26	0.826
5	0.757 gm. irradiated yeast	26.5	85	7	162	133	17.7	1.87	458±42	57.7±0.45	0.700
6	1.514 gm. irradiated yeast	53.0	197	6	200	158	19.3	2.02	750±71	60.4±0.73	0.767
7	3.028 gm. irradiated yeast	106.0	488	7	224	174	20.0	2.10	890±36	62.7±0.37	0.808
8	6.056 gm. irradiated yeast	212.0	1083	6	246	190	20.6	2.26	1084±86	64.0±0.25	0.833

*The number of pigs on which the femur measurements and analyses were based.

†Standard error of mean.

difference to show up most markedly at sub-optimum levels of intake. All of the femur data from the two lowest cod-liver oil (lots 2 and 3) and irradiated yeast-fed lots (5 and 6) show no significant differences when nearly comparable levels of the two sources of vitamin D are compared.

The calcium content of the blood serum (table 8) of the pigs fed rations that contained less than 90 U. S. P. units of vitamin D per pound of feed either from cod-liver oil or irradiated yeast decreased progressively during the test. The rate and extent of decrease from period to period was directly correlated with the vitamin D content of the ration. It required 90 U. S. P. units or more of vitamin D per pound of feed from either cod-liver oil or irradiated yeast to maintain a uniform calcium level in the blood serum throughout the test. The results, in this respect, are in accord with the live weight gain, feed requirement, (table 6) and femur data (table 7).

The phosphatase values of the blood serum (table 8) increased when the level of vitamin D was inadequate, as judged by general performance, breaking strength and ash content of the femurs, and calcium levels in the blood. The rate and extent of increase or decrease in phosphatase values of the serum was more or less proportional to the amount of vitamin D in the ration. Although the phosphatase values are not as clear-cut as the calcium values, it will be noted that it required 90 U. S. P. units or more of vitamin D per pound of feed from either cod-liver oil or irradiated yeast to prevent any increase in phosphatase levels of the serum throughout the experiment. It is also of interest to note that the average phosphatase values decreased progressively with age or time on experiment when the level of vitamin D intake was adequate to prevent any indications of rickets. The high average phosphatase value observed in lot 5 during the twelfth week was due chiefly to the two animals which died in this lot between the twelfth and sixteenth weeks.

The inorganic phosphorus content of the blood serum (table 8) was not greatly affected by the level of vitamin D feeding. However, there was an indication that the phosphorus was decreased when no vitamin D was fed (lot 1). The increase in the average phosphorus in lot 1 (basal ration) from 5.8 to 8.1 milligrams between the twelfth and sixteenth weeks was probably due to partial starvation. The two pigs in this lot which survived to the completion of the test consumed very little feed and lost weight from the twelfth week to the close of the trial. Similar increases in blood inorganic phosphorus content have been noted in case of rachitic rats which do not consume enough feed to maintain their weight.

The blood studies show no significant difference in the effectiveness of vitamin D from either cod-liver oil or irradiated yeast in maintaining the calcium, inorganic phosphorus, and phosphatase content of the serum. The results in this respect are in agreement with live weight gain and feed requirement data (table 6) and the physical measurement and ash data of the femurs (table 7).

Trial 4

The pigs in this trial were from crossbred gilts (Duroc Jersey × Poland China × Hampshire) all bred to the same Duroc Jersey boar. They were farrowed in early spring and reared under the same nutritional environment including access to pasture. When the pigs were 8 to 10 weeks old, they were divided into eight lots of seven pigs each and confined to individual experimental pens. All pigs were fed the basal ration (ration 2) for 4 weeks before

TABLE 8.—The average calcium, inorganic phosphorus, and phosphatase contents of the blood serum. Trial 3

Lot No.	Vitamin D supplement additions per 100 lb. basal ration	Vitamin D per lb. feed	Av. daily intake of vitamin D	Av. calcium (mg.) per 100 ml. serum					Av. phosphorus (mg.) per 100 ml. serum					Av. phosphatase (units) per ml. serum				
				Start	4 wks.	8 wks.	12 wks.	16 wks.	Start	4 wks.	8 wks.	12 wks.	16 wks.	Start	4 wks.	8 wks.	12 wks.	16 wks.
		Units	*Units*															
1......	None	0	0	12.4	7.7*	6.8‡	7.5§	6.3‖	8.2	9.6*	8.1‡	5.8§	8.1†	7.1	14.8*	10.8‡	14.1§	10.7‖
2......	10.000 gm. cod-liver oil....	22.5	78	12.4	10.0	9.5	8.5	7.7*	8.3	8.3	8.4	8.7	9.5*	7.1	13.4	12.0	11.3	12.2*
3......	20.000 gm. cod-liver oil..........	45.0	208	12.4	11.9	12.2	11.0†	10.5†	8.9	8.2	8.5	8.6†	9.4†	6.8	11.6	10.1	8.1†	7.2†
4......	40.000 gm. cod-liver oil..........	90.0	418	12.0	12.8	12.8	12.0	12.7	7.7	9.4	9.8	9.2	10.9	7.5	7.9	7.6	6.2	4.7
5......	0.757 gm. irradiated yeast.......	26.5	85	12.8	10.6	9.1	7.8	7.9†	8.5	9.5	8.2	7.7	8.3†	7.8	13.4	13.2	17.0	14.8†
6......	1.514 gm. irradiated yeast.......	53.0	197	12.2	12.0	11.5	10.7	10.5	8.7	9.2	8.7	8.9	9.9	7.2	11.2	8.6	8.3	7.8
7......	3.028 gm. irradiated yeast.......	106.0	488	12.4	12.7	12.6	12.1	12.3	8.4	9.9	9.6	9.4	10.4	7.2	7.3	6.4	5.7	4.1
8......	6.056 gm. irradiated yeast.......	212.0	1083	12.4	12.2	12.2	12.2	12.9	8.6	9.4	9.2	10.0	9.9	7.1	7.9	6.6	5.6	4.3

The average values for lots 4 and 7 are based on seven pigs each; for lots 6 and 8, on six pigs each; and for the other lots as follows: *6 pigs; †5 pigs; ‡4 pigs; §3 pigs; ‖2 pigs.

varying amounts of cod-liver oil and irradiated yeast were added. One lot was continued on the basal ration. The experimental rations (table 9) were fed for 16 weeks—starting July 8 and terminating October 28.

One pig on the basal ration (lot 1) exhibited signs of stiffness by the eighth week but continued to live until the eighty-ninth day, when it was found dead in its pen. Post-mortem examinations showed a slight congestion of all internal organs and an enlargement of the costo-chondral junctions. The calcium content of the blood serum of this pig 5 days prior to death was 5.97 milligrams per 100 milliliters in contrast to an average of 9.26 milligrams for the other six pigs in the lot—suggesting that the pig might have died from tetany. Another pig in the same lot showed gross rachitic symptoms in the form of stiffness by the thirteenth week. A third animal gave evidence of slight stiffness by the fifteenth week. The four remaining pigs in lot 1 completed the test without showing any external symptoms of a vitamin D deficiency.

One pig in each of lots 2 and 5 (22.5 and 26.5 U. S. P. units of vitamin D per pound of feed from cod-liver oil and irradiated yeast, respectively) showed signs of slight stiffness by the eighth week of vitamin D feeding. The condition did not appear to change before the test was terminated. The remaining pigs in lots 2 and 5, as well as those in the other vitamin D-fed lots (lots 3, 4, 6, 7, and 8) completed the experiment without showing any external symptoms of a vitamin D deficiency. A pig in lot 8 died during the thirteenth week from a strangulated hernia. Up to 2 days before death, this pig gave every indication of being normal.

The performance data of the different lots (table 9) show that it required more than 26.5 U. S. P. units of vitamin D per pound of feed to attain a maximum average daily gain. However, the amount of feed required for each 100 pounds of gain in live weight was not significantly lowered by the inclusion of more than 22.5 units of vitamin D per pound of feed. The gain, feed requirement, and general performance data (table 9) indicate that the two forms of vitamin D were approximately equally effective.

The physical measurement and ash data of the femurs, presented in table 10, show that it required approximately 45 U. S. P. units of vitamin D per pound of feed to give maximum breaking strength and bone ash values. The data also show that the forms of vitamin D in irradiated yeast and in cod-liver oil are approximately equal for bone growth and calcification, since nearly comparable but sub-optimum levels (22.5 and 26.5 U. S. P. units of vitamin D per pound of feed from cod-liver oil lot 2 and irradiated yeast lot 5, respectively), gave the same results.

The average results of the periodic determinations of calcium, inorganic phosphorus, and phosphatase in the blood serum of the individual pigs are presented in table 11. A progressive decrease in the average calcium content and an increase in the average phosphatase values occurred in the control or no vitamin D-fed lot (lot 1). There is also an indication that the lowest levels of cod-liver oil (lot 2) and irradiated yeast (lot 5) were not quite adequate to maintain optimum calcium and phosphatase values. The decrease in the calcium content and increase in the phosphatase values of the serum on sub-optimum levels of vitamin D supplementation were not as marked in this trial as those observed in trial 3 (table 8). The average inorganic phosphorus value of the blood serum did not show any effect either due to level or source of vitamin D feeding and are very similar to the results obtained in trial 3 (table 8).

TABLE 9.—Gains and feed requirements. Trial 4

Lot No.	Vitamin D supplement additions per 100 lb. basal ration	Vitamin D per lb. feed	Av. daily intake of vitamin D	Pigs per lot	Pigs died	Av.† initial weight	Av.* final weight	Av.* daily gain	Av.* daily feed	Feed required per 100 lb. gain	Remarks
		Units	*Units*	*No.*	*No.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	
1.........	None	0	0	7	1	62.6	185.5	1.10	4.20	388	Two were stiff; one was slightly stiff.
2.........	10.000 gm. cod-liver oil......	22.5	99	7	0	62.9	202.9	1.25	4.39	352	One was slightly stiff.
3.........	20.000 gm. cod-liver oil......	45.0	215	7	0	62.9	213.8	1.35	4.77	354	Normal.
4.........	40.000 gm. cod-liver oil.....	90.0	457	7	0	63.4	222.9	1.42	5.08	358	Normal.
5.........	0.757 gm. irradiated yeast..	26.5	121	7	0	62.8	206.2	1.28	4.57	358	One was slightly stiff.
6.........	1.514 gm. irradiated yeast..	53.0	242	7	0	60.6	210.0	1.33	4.57	342	Normal.
7.........	3.028 gm. irradiated yeast..	106.0	514	7	0	62.3	217.9	1.39	4.85	350	Normal.
8.........	6.056 gm. irradiated yeast..	212.0	1009	7	1	62.3	211.5	1.32	4.76	359	Normal.

*On basis of pigs living at close of trial.
†Weights when supplemental feeding started. The average initial weights when put on the basal ration were 37.6, 37.4, 36.4, 37.4, 35.7, 35.7, 36.6, and 37.1 pounds for lots 1 to 8, respectively.

TABLE 10.—Physical measurements and ash content of femurs. Trial 4

Lot No.	Vitamin D supplement additions per 100 lb. basal ration	Vitamin D per lb. feed	Av. daily intake of vitamin D	Pigs per lot*	Av. weight	Av. volume	Av. length	Av. smallest diameter	Av. breaking strength	Av. ash	Av. ash per cc. volume
		Units	*Units*	*No.*	*Gm.*	*Cc.*	*Cm.*	*Cm.*	*Lb.*	*Pct.*	*Gm.*
1.......	None	0	0	7	181	151	19.3	1.85	737±80†	59.3±0.92†	0.704
2.......	10.000 gm. cod-liver oil................	22.5	99	7	214	175	20.4	1.94	906±95	61.0±0.69	0.744
3.......	20.000 gm. cod-liver oil................	45.0	215	7	223	177	20.7	1.99	1044±59	63.1±0.37	0.794
4.......	40.000 gm. cod-liver oil	90.0	457	7	232	185	20.7	2.03	1047±71	63.5±0.32	0.794
5.......	0.757 gm. irradiated yeast.............	26.5	121	7	217	179	20.3	1.96	889±87	60.5±0.90	0.735
6.......	1.514 gm. irradiated yeast............	53.0	242	7	223	180	20.3	2.03	1127±81	62.2±0.30	0.774
7.......	3.028 gm. irradiated yeast............	106.0	514	7	238	189	20.8	2.10	1107±55	62.7±0.44	0.788
8.......	6.056 gm. irradiated yeast............	212.0	1009	6	221	176	20.3	1.97	1030±90	63.0±0.38	0.791

*The number of pigs on which the femur measurements and analyses were based.
†Standard error of mean.

TABLE 11.—The average calcium, inorganic phosphorus, and phosphatase contents of the blood serum. Trial 4

Lot No.	Vitamin D supplement additions per 100 lb. basal ration	Vitamin D per lb. feed	Av. daily intake of vitamin D	Av. calcium (mg.) per 100 ml. serum					Av. phosphorus (mg.) per 100 ml. serum					Av. phosphatase (units) per 100 ml. serum				
				Start	4 wks.	8 wks.	12 wks.	16 wks.	Start	4 wks.	8 wks.	12 wks.	16 wks.	Start	4 wks.	8 wks.	12 wks.	16 wks.
		Units	*Units*															
1.......	None	0	0	11.9	10.9	9.6	8.8	8.7*	11.2	10.6	11.1	9.4	10.0*	6.7	7.8	10.5	11.3	9.8*
2.......	10.000 gm. cod-liver oil..........	22.5	99	11.7	12.0	11.3	11.1	11.4	11.0	11.1	10.9	9.5	9.8	8.3	6.5	7.4	5.8	5.3
3.......	20.000 gm. cod-liver oil.........	45.0	215	11.5	11.9	11.8	11.7	12.5	10.7	11.0	10.8	10.1	10.0	6.9	7.1	6.4	4.2	4.2
4.......	40.000 gm. cod-liver oil	90.0	457	11.7	11.5	12.1	12.1	12.9	11.5	10.9	11.0	10.0	10.1	7.3	6.1	4.7	3.8	3.7
5.......	0.757 gm. irradiated yeast	26.5	121	11.9	12.2	11.1	10.6	11.0	10.9	10.5	10.6	9.2	10.0	9.1	6.3	7.8	8.2	7.0
6.......	1.514 gm. irradiated yeast.......	53.0	242	11.9	12.0	11.8	12.1	13.1	10.8	10.0	10.1	9.3	10.1	7.2	6.3	6.8	6.1	4.9
7.......	3.028 gm. irradiated yeast.......	106.0	514	12.2	12.1	12.3	12.6	12.7	10.3	9.8	10.4	9.8	10.3	7.6	7.3	6.4	4.7	3.5
8.......	6.056 gm. irradiated yeast.......	212.0	1009	11.8	11.9	12.0	11.7	12.7*	10.6	9.7	10.7	9.8	9.7*	7.5	6.0	6.5	4.6	3.7*

*Average value based on six pigs; all other values on basis of seven pigs.

The blood serum determinations do not show any difference in the effectiveness of vitamin D either from cod-liver oil or irradiated yeast in maintaining normal calcium, inorganic phosphorus, and phosphatase values of the blood. The results of the blood serum studies are, in general, in accord with the performance and femur analyses results.

Trial 5

The pigs in trial 5 were from crossbred (Duroc Jersey × Poland China) sows bred to the same Hampshire boar. They were farrowed in late summer and reared on pasture under the same management and feeding practices. When they were 8 to 10 weeks old, they were confined indoors and fed basal ration 2 for 25 days. Following the preliminary feeding period the pigs were divided into five lots of seven each and confined to individual pens. One lot was continued on basal ration 2. Two lots were fed the basal ration supplemented with 45 and 90 U. S. P. units of vitamin D per pound of feed from cod-liver oil. The other two lots were fed the basal ration supplemented with 45.5 and 91 U. S. P. units of vitamin D per pound of feed from irradiated yeast. The experimental rations were fed for 17 weeks—starting November 11 and terminating March 10.

All of the pigs started lived throughout the test. One pig on the unsupplemented basal ration (lot 1) showed stiffness by the ninth week, which became progressively worse during the remainder of the trial. Three other pigs in the same lot (lot 1) exhibited vitamin D deficiency in the form of stiffness of the legs by the fifteenth week. A fifth pig gave evidence of slight stiffness shortly before the close of the trial. The other two pigs on the basal ration (lot 1) completed the test without showing external symptoms of a vitamin D deficiency.

Two pigs in the lowest cod-liver oil-fed lot (lot 2, 45 U. S. P. units of vitamin D per pound of feed) showed a slight stiffness after 14 and 15 weeks on the experimental ration. Another pig in lot 2 developed an umbilical hernia but continued to make good gains to the close of the trial. No gross symptoms, indicative of vitamin D deficiency, were observed in any of the pigs in lots 3, 4, and 5.

From the live weight gain and feed requirement data presented in table 12, it is evident that supplementing the basal ration with vitamin D, either in the form of cod-liver oil or irradiated yeast, increased the rate of gain and decreased the amount of feed required per unit of gain. Although the average daily gains and the amount of feed required per unit of gain were not affected by including more than 45 U. S. P. units of vitamin D per pound of feed, either from cod-liver oil or irradiated yeast, the appearance of slight stiffness in two of the seven pigs in lot 2 suggests that more than the above amount of vitamin D per pound of feed was required for complete protection against any symptoms of a deficiency. The gain and feed requirement data (table 12) also indicate that there was no great difference in the effectiveness of the two forms of vitamin D.

The results of the average physical measurements and ash contents of the femurs, given in table 13, show that it required more than 45 U. S. P. units of vitamin D per pound of feed from either cod-liver oil or irradiated yeast to produce bones of optimum breaking strength and ash content. The results also show that comparable levels of vitamin D per pound of feed from either cod-liver oil or irradiated yeast were equally effective in promoting bone growth and calcification.

TABLE 12.—Gains and feed requirements. Trial 5

Lot No.	Vitamin D supplement additions per 100 lb. basal ration	Vitamin D per lb. feed	Av. daily intake of vitamin D	Pigs per lot	Pigs died	Av. initial weight	Av. final weight	Av. daily gain	Av. daily feed	Feed required per 100 lb. gain	Remarks
		Units	*Units*	*No.*	*No.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	
1	None	0	0	7	0	58.6	169.8	0.93	3.92	428	Four stiff; one slightly stiff.
2	20.00 gm. cod-liver oil	45.0	213	7	0	61.2	211.2	1.26	4.74	379	Two slightly stiff.
3	40.00 gm. cod-liver oil	90.0	436	7	0	60.5	218.5	1.33	4.85	368	Normal.
4	1.30 gm. irradiated yeast	45.5	228	7	0	58.6	221.4	1.37	5.02	368	Normal.
5	2.60 gm. irradiated yeast	91.0	422	7	0	61.1	213.0	1.28	4.64	364	Normal.

TABLE 13.—Physical measurements and ash content of femurs. Trial 5

Lot No.	Vitamin D supplement additions per 100 lb. basal ration	Vitamin D per lb. feed	Av. daily intake of vitamin D	Pigs per lot*	Av. weight	Av. volume	Av. length	Av. smallest diameter	Av. breaking strength	Av. ash	Av. ash per cc. volume
		Units	*Units*	*No.*	*Gm.*	*Cc.*	*Cm.*	*Cm.*	*Lb.*	*Pct.*	*Gm.*
1	None	0	0	7	165	146	18.9	1.92	520±85†	56.6±1.05†	0.646
2	20.00 gm. cod-liver oil	45.0	213	7	203	169	19.9	2.02	765±70	61.2±0.74	0.732
3	40.00 gm. cod-liver oil	90.0	436	7	211	170	20.3	2.05	892±47	62.8±0.43	0.778
4	1.30 gm. irradiated yeast	45.5	228	7	202	168	19.8	2.00	790±67	61.2±0.47	0.736
5	2.60 gm. irradiated yeast	91.0	422	7	210	170	20.0	2.06	900±78	62.6±0.41	0.773

*The number of pigs on which the femur measurements and analyses were based.
†Standard error of mean.

TABLE 14.—The average calcium, inorganic phosphorus, and phosphatase contents of the blood serum. Trial 5

Lot No.	Vitamin D supplement additions per 100 lb. basal ration	Vitamin D per lb. feed	Av. daily intake of vitamin D	*Av. calcium (mg.) per 100 ml. serum					*Av. phosphorus (mg.) per 100 ml. serum					*Av. phosphatase (units) per 100 ml. serum				
				Start	4 wks.	8 wks.	12 wks.	16 wks.	Start	4 wks.	8 wks.	12 wks.	16 wks.	Start	4 wks.	8 wks.	12 wks.	16 wks.
		Units	*Units*															
1	None	0	0	12.3	11.6	10.6	10.1	8.0	8.8	8.9	9.6	8.5	9.4	3.7	5.1	8.5	8.8	13.3
2	20.000 gm. cod-liver oil	45.0	213	12.5	11.9	11.9	12.2	12.1	8.0	8.8	10.1	9.1	9.4	5.0	4.5	7.9	6.8	7.5
3	40.000 gm. cod-liver oil	90.0	436	12.4	11.9	13.0	12.9	12.7	8.6	9.1	10.3	10.3	9.9	4.1	4.6	5.5	3.5	4.9
4	1.30 gm. irradiated yeast	45.5	228	12.2	12.1	11.8	12.6	11.9	8.4	8.1	8.8	8.1	9.1	3.4	4.1	6.4	6.4	5.7
5	2.60 gm. irradiated yeast	91.0	422	12.4	12.0	12.0	12.9	12.8	9.3	9.3	8.8	9.9	10.2	3.9	3.8	6.2	4.8	4.7

*Average values based on seven pigs per lot.

The average of the individual determinations made on the blood serum of the pigs in this trial (table 14) show, as in former trials with the same basal ration (trials 3 and 4), a progressive decrease in the calcium content and an increase in the phosphatase content of the serum as the animals were continued on the unsupplemented basal ration (lot 1).

The inorganic phosphorus content of the blood serum was not affected by vitamin D feeding. The results also indicate that 45 U. S. P. units of vitamin D per pound of feed were adequate to maintain a normal uniform calcium content of the serum. The average phosphatase values, on the contrary, indicate that somewhat more than 45 U. S. P. units of vitamin D per pound of feed were required to prevent some increase in those values during the course of the experiment. The results of the calcium and phosphatase determinations on the blood serum indicate that the form of vitamin D in irradiated yeast was as effective as the form in cod-liver oil.

A general consideration of all data indicates that the minimum vitamin D requirements of the pigs used in this trial were somewhat more than 45 U. S. P. units of vitamin D per pound of feed and that the form of vitamin D in cod-liver oil and in irradiated yeast were equally efficient for growth, feed utilization, bone growth and calcification, and for maintaining the calcium and phosphatase content of the blood serum.

Discussion

The results of the foregoing experiments substantiate the observations of other investigators that vitamin D is essential in swine nutrition. The data also show, in conformity with the observations of Johnson and Palmer (9) and Senior (16), that swine have a fundamental requirement for vitamin D even when the feed supplies adequate amounts of calcium and phosphorus and in a satisfactory ratio.

A comparison of the results obtained in the several trials shows that the vitamin D requirements of pigs are variable. In trial 1, the over-all results indicate that a minimum of about 44 U. S. P. units of vitamin D per pound of ration were required to produce optimum growth and feed utilization, bones with a maximum breaking strength and ash content, and a normal blood serum picture. Another group of pigs on the same basal ration (trial 2) required the addition of about 67 U. S. P. units of vitamin D per pound of ration to prevent the appearance of vitamin D deficiency symptoms. On the basis of vitamin D supplementation per pound of ration, these results indicate that the pigs in trial 2 required approximately 50 percent more vitamin D per pound of ration than the pigs in trial 1. However, on the basis of actual average daily vitamin D intake, the difference is only on the order of 31 percent. The pigs in trial 2 had an average daily intake of 252 U. S. P. units compared to 193 U. S. P. units for the pigs in trial 1.

Similar variations in the minimum amounts of vitamin D that were required per pound of ration to insure against a deficiency were noted in the other three trials. The over-all results of trial 4, in which spring farrowed pigs were used, indicated that the requirements were on the order of 45 U. S. P. units per pound of ration or an average daily intake for the test of 215 U. S. P. units. In contrast, the results obtained with the fall-farrowed pigs in trial 3 indicate a minimum requirement of 90 U. S. P. units per pound of ration, or an average daily per head intake of about 418 U. S. P. units for the test.

Likewise, the results obtained with the early fall-farrowed pigs in trial 5 show that somewhat more than 45 U. S. P. units of added vitamin D per pound of ration, or an average daily per head intake of more than 215 U. S. P. units, were required to produce bones of maximum strength and ash content and to maintain a normal calcium and phosphatase content in the blood serum.

The variation noted in the vitamin D requirements between the different groups of pigs on the same basal ration as well as the variation between individual pigs of the same breeding and preexperimental nutritional history is, in a large measure, due to a variable storage of vitamin D in the pigs before they were put on experiment. All pigs used in these trials were reared out-of-doors and therefore had the opportunity of storing vitamin D by exposure to sunshine. The amount of vitamin D stored would naturally be affected by the intensity of the sunshine and the length of exposure.

Johnson and Palmer (8) have presented evidence that breed or possibly pigmentation was a factor in the amount of vitamin D required or stored by pigs. Their work showed that pigs with dark pigmentation stored less vitamin D, as judged by the time required to produce rachitic symptoms, than nonpigmented pigs reared under the same conditions. An examination of our records with regard to the possible relation of pigmentation or hair color to the time of appearance of rachitic symptoms or the amount of added vitamin D required to prevent symptoms, show relationships similar to those reported by Johnson and Palmer (8). Most frequently those pigs in a trial which showed the first symptoms of a vitamin D deficiency were of dark hair color or conversely those pigs in a trial which showed mild or no deficiency symptoms were frequently of a much lighter hair color with little pigmentation of the skin. It is of interest, in this connection, that the severest rachitic symptoms and the highest vitamin D requirements were observed in trial 3, in which fall-farrowed crossbred (Hampshire × Berkshire) pigs were used.

A consideration of the results obtained in the five separate trials indicates that the forms of vitamin D in irradiated yeast and in cod-liver oil are approximately equally effective for growing swine. Although the results obtained in trial 2 indicate that vitamin D from cod-liver oil is more effective than that from irradiated yeast, it is our judgment that the over-all results of the other trials show the two forms of vitamin D to be approximately equally effective.

Although the amounts of supplemental vitamin D needed to give complete protection against a deficiency varied in the five trials, it is evident that under the experimental conditions employed, the minimum practical vitamin D requirements of growing pigs to market weight are approximately 90 U. S. P. units per pound of ration. This amount is considerably greater than the values reported by Johnson and Palmer (9). They reported that 19 to 20 U. S. P. units of vitamin D from sun-cured alfalfa hay per pound of ration protected against rickets but failed to cure the deficiency; whereas 33 U. S. P. units per pound of ration cured rickets. These investigators used a basal ration which contained 1.07 percent calcium and 0.65 percent phosphorus, while the basal ration (ration 2) we used analyzed from 0.56 to 0.60 percent calcium and 0.45 to 0.49 percent phosphorus. It has been shown that the need of swine for vitamin D is, within limits, inversely proportional to the calcium and phosphorus content of the ration. Accordingly, the actual vitamin D requirements on the Johnson and Palmer ration would be less than on ration 2 used in the present investigations. Another point to consider in comparing the observations of Johnson and Palmer (9) with the present findings is the criteria used in establishing requirements. The Minnesota investigators relied upon external symptoms and blood calcium and phosphorus determinations. No bone studies were made. It has been our experience that external symptoms and/or blood analyses can not always be relied on as an index of adequacy of vitamin D if maximum calcification of the bones, as judged by breaking strength and ash content, on a particular ration are considered essential.

The results obtained with ration 1, containing 1.16 percent calcium and 0.4 percent phosphorus giving a calcium : phosphorus ratio of 2.90, did not show a higher added vitamin D requirement than the results with ration 2, which analyzed 0.56 to 0.60 percent calcium and 0.45 to 0.49 percent phosphorus, or an average calcium : phosphorus ratio of 1.24. This observation might be construed as being in contradiction with a previous report from this station (3) that the pigs' requirement for vitamin D increased when the calcium : phosphorus ratio of the ration was about 3.0 or greater. The present observations, in this respect, cannot be compared directly with the previous (3) findings. In the present trials, pigs of different nutritional history were used in each trial, whereas in the earlier experiments on the effects of the calcium-phosphorus relationship to vitamin D requirements, pigs of the same nutritional history were compared.

A comparison of the two basal rations brings out certain differences in the calcium and phosphorus content of the blood serum and the breaking strength and ash content of the femurs. The calcium and phosphorus blood serum values on basal ration 1, when supplemented with adequate vitamin D, were on the order of 14.5 to 15.5 and 5.0 to 6.5 milligrams per 100 milliliters of serum, respectively, in contrast to calcium values of 12 to 13 milligrams and of phosphorus values of 9 to 10 milligrams per 100 milliliters of serum in the case of basal ration 2. The maximum average breaking strength of the femurs on basal ration 1 varied between 600 and 700 pounds; whereas, with basal ration 2, the maximum values varied between 900 and 1,100 pounds. Similarly, the average maximum ash present in the femurs was greater on ration 2 than on ration 1. The maximum ash values on ration 1 varied between 59 and 61 percent, while in case of ration 2, the average maximum values were 61 percent or greater. These results are in accord with other unpublished observations on the relationships of the calcium and phosphorus content of the ration to blood serum composition and strength and ash content of the bones of growing pigs.

From a practical standpoint, the results reemphasize the importance of vitamin D in efficient pork production and show that either irradiated yeast or cod-liver oil can serve as an effective source of vitamin D in swine nutrition. The choice, therefore, depends upon the relative cost of the two forms.

Summary

Five separate trials, involving 258 pigs and two basal rations, were conducted indoors in the absence of direct sunshine to obtain information on the vitamin D requirements of growing pigs and on the comparative effectiveness of vitamin D from irradiated yeast and cod-liver oil.

The results of the five trials, as judged by growth, feed required per unit of gain, gross rachitic symptoms, physical determinations and ash analysis on the femurs, and blood serum analysis for calcium, inorganic phosphorus, and phosphatase showed that:

(1) The growing pig has a fundamental requirement for vitamin D.

(2) The minimum practical vitamin D requirement of growing pigs fed a ration containing approximately 0.6 percent calcium and 0.45 percent phosphorus is on the order of 90 U. S. P. units per pound of ration.

(3) The forms of vitamin D in irradiated yeast and cod-liver oil are essentially equally effective for swine, unit for unit.

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